

MATCHING WITH A KEY-PECK RESPONSE IN CONCURRENT NEGATIVE REINFORCEMENT SCHEDULES¹

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In the absence of responding, pigeons were shocked under a variable-time schedule. Responses on either of two keys occasionally produced one minute of shock-free time. That is, pigeons' key pecks were reinforced with shock-free time under concurrent variable-interval schedules. The relative frequency of access to the one-minute shock-free periods was systematically manipulated. Pigeons tended to match both relative response rate and proportion of time spent on each key to the relative frequency of the shock-free periods. A best-fit linear regression equation accounted for over 95% of the variance in both relative response rate and time allocation. The data paralleled closely the results of concurrent schedules of positive reinforcement. These findings are consistent with a description of reinforcement as a transition to a higher-valued situation and suggest that common laws govern choice for both positive and negative reinforcement.

Key words: avoidance, negative reinforcement, concurrent schedules, matching law, law of effect, key pecking, pigeons

According to the matching law (Herrnstein, 1970) the rate of response controlled by a reinforcing alternative is equal to the proportion of reinforcers delivered for that alternative. This can be expressed as a relative rate by

$$\frac{B_1}{B_2} = \frac{r_1}{r_2}, \quad (1)$$

in which B_1 and B_2 represent the response rates associated with the two alternatives. The reinforcement value associated with alternative one and alternative two are represented by r_1 and r_2 , respectively. If r_1 and r_2 are expressed as rate of reinforcement, Equation 1 predicts that relative response rate will be equal to the relative rate of reinforcement.

Although Equation 1 is an empirical generalization based on the results of experiments involving positive reinforcement, a recent modification of the law of effect (Baum, 1973) applies also to experiments involving aversive stimuli. Baum defined reinforcement as a transition from a low-valued situation to a higher-

valued situation where value is a scale that represents the parameters of reinforcement and punishment. For example, 4 sec of access to grain, in many cases, has greater "value" to a hungry pigeon than a situation in which grain is not available. The transition from a situation of lower value (a no-food situation) to a situation of higher value (4 sec of access to grain) would, therefore, serve as a positive-valued transition and reinforce behavior that is correlated with it. The value (or relative reinforcing property) of any situation with respect to any other situation must be empirically determined. However, once a reinforcer (positive-valued transition) has been identified, Equation 1 predicts that the relative response rate will match the relative rate of access to that transition. A similar analysis can be made of negative reinforcement procedures.

For example, past experiments (Lewis, Lewin, Stoyak, and Muehleisen, 1974; Lewis, Moon, and Hutton, 1976) show that shock-free periods reinforce key pecking in pigeons. In these experiments, shock occurred in the presence of one situation, and a peck produced a different situation in which no shock occurred. Both situations were associated with distinctive stimuli. The transition from the first to the second situation was reinforcing. In another experiment, using negative reinforcement, the absolute response rate decreased as the value of the

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transition decreased, even though the consequence for pecking remained the same (Hutton and Lewis, *in press*).

The question in the present experiment was: does the relative frequency of 1-min shock-free periods produced for pecking on one key affect the relative number of responses and relative time spent on that key in a concurrent schedule? In particular, does relative rate of key pecking "match" the relative frequency of shock-free time presented as a consequence for key pecking?

The procedure was comparable to a concurrent VI-VI schedule of food reinforcement. Instead of, say, 4 sec access to grain as a consequence of pecking, pigeons produced 1 min of shock-free time. The independent variable was the relative frequency of shock-free periods following a response on one key, and the dependent variable was the relative frequency with which that key was pecked.

METHOD

Subjects

Three White Carneaux pigeons (M1, M3, and M4) from the Palmetto Pigeon farm, Sumter, South Carolina, were maintained at 80% of their free-feeding weights during initial training; thereafter, subjects were given free access to food and water in their home cages. The subjects were naive when they began the training procedure, described below, but between the training and the experimental procedures, all three pigeons participated briefly in a concurrent negative-reinforcement experiment involving delayed shocks.

Apparatus

A standard conditioning chamber (BRS-LVE) with two translucent response keys, which could be illuminated white, red, or green, was housed in a sound-attenuating box. The two keys were positioned 25 cm from the floor and 20.3 cm apart. A response of 0.44 N on either key closed a microswitch. The food reinforcer, 4-sec access to mixed grain, was delivered with the houselights out. A variable ac transformer in series with a 10 K-ohm resistor delivered shocks for 0.3 sec. Shock was carried to stainless-steel electrodes implanted around the pigeon's pubis bone (Azrin, 1959). The implanted wires were routed vertically from the pubis bone, posterior to the bird's legs. A Nu-

way snap was crimped to each wire. From these snaps, a two-conductor cable led to a two-conductor plug held above the pigeon's back by a thin leather harness. During experimental sessions, the plug was connected to a mercury commutator (Gerbrands, Inc.) mounted on the ceiling of the chamber. White masking noise (80 dB) was present throughout each session, and a 10-cps click stimulus (85 dB) was provided by a BRS-LVE module when required. Solid-state scheduling and recording equipment was located in an adjacent room.

Procedure

Training. Pigeons were trained to avoid by the reinforcement-switching method (see Lewis *et al.*, 1974). During the training sessions, subjects were tested for 2 hr or until 50 food reinforcers occurred, whichever came first. Subjects were trained to peck both response keys by reinforcing approximations. Next, a concurrent two-component chain schedule was introduced. During the first component, both keys were white and the clicker was on; during the second component, one key was dark and either the left key was green or the right key was red. After 10 sec in the presence of the first component, a peck on one of the white keys terminated the clicker, changed the key color on that key, and darkened the other key. The schedule in the initial component was therefore FI 10-sec. The second component was 3 min long. During the second component, pecking produced grain at variable intervals averaging once every 10 sec (VI 10-sec). All VI schedules included two sequences of 10 intervals generated from Fleshler and Hoffman (1962) tables. The size of the variable-interval food schedule was subsequently increased to VI 15-sec, VI 30-sec, and VI 60-sec. After responding was maintained on *conc* chain FI 10-sec VI 60-sec, shocks of 10-V intensity and 0.3 sec in duration were delivered during the first component at varying time intervals averaging once every 3 sec (VT 3-sec). Throughout the experiment, shocks were inescapable. Next, shock intensity was increased daily in 10-V increments from 10 V to 70 V (M4) or to 120 V (M1 and M3). Then, the VI food schedule was gradually eliminated (VI 60-sec, VI 120-sec, VI 300-sec, VI 600-sec; after VI 600-sec, all food was eliminated). Following food elimination, duration of the second component was reduced from 3 min to 2 min to 1 min; the first com-

ponent shock schedule was changed from VT 3-sec to VT 5.4-sec; finally, the first component schedule requirement was changed from VI 10-sec to VI 20-sec, then VI 45-sec.

Experimental condition. Subjects were tested every other day for either 2.5 hr (M1 and M3) or 5.0 hr (M4). The first procedure was *conc* VI 1-min VI 1-min. Reinforcement was a 1-min shock-free period. In the absence of a response, both keys were white, the clicker on, and shock was delivered under a VT 5.4-sec schedule. Reinforcement was scheduled by separate VI programmers, one for each key; both VI timers ran continuously. A peck on a key, whose associated variable interval was completed, changed the color of that key from white to red (right key) or white to green (left key), darkened the other key, and terminated the clicker and the 5.4-sec shock schedule for 1 min. When the keys were white, the clicker on, and the shock schedule in effect, the procedure was called the initial link. Responses during the 1-min reinforcement period were recorded, but had no other effect.

The order of conditions and the VI schedules of reinforcement associated with each key are in Table 1. Because the overall rate of reinforcement might have affected the sensitivity of the dependent variable to changes in the independent variable, it was held constant at a nominal value of 3.56 per minute throughout the experiment (Baum, 1974). This rate was sometimes exceeded, however, since the VI tapes ran continuously and since the tapes were rarely at the beginning of an interval when timing began. The obtained mean reinforcement rate and the range for the last five sessions of each condition are in Table 2. The scheduled relative rate of reinforcement (right key/left key) was 0.33, 0.11, 0.33, 1.00, 3.00, 9.00, 3.00, and 1.00 for Conditions 1 through 8, respectively.

Subjects M1 and M3 were tested for 10 sessions under each condition, and M4 was tested for seven sessions under each condition.

Dependent variables were absolute response rate (total pecks on both keys during the initial link divided by the length of the initial link), relative response rate (pecks on one key divided by pecks on the other key during the initial link), and a time-allocation measure. Time allocation was measured with two clocks—one for the left key and one for the right key. The first key peck on either key in the presence

Table 1
Order of Variable-Interval Reinforcement Schedules

<i>Schedule on Left Key (sec)</i>	<i>Schedule on Right Key (sec)</i>
VI 67.50	VI 22.50
VI 168.50	VI 18.50
VI 67.50	VI 22.50
VI 33.75	VI 33.75
VI 22.50	VI 67.50
VI 18.50	VI 168.50
VI 22.50	VI 67.50
VI 33.75	VI 33.75

of the shock condition activated the clock for that key. Further responses on the same key had no effect on the clocks, but a response on the other key terminated the first clock and activated the clock associated with that key. The clocks did not operate during the 1-min reinforcement periods or until after the first response following onset of each shock condition.

No changeover delay (COD) was used in either training or in the experimental conditions. In other experiments with a COD, pigeons had developed exclusive preferences for the more frequent negative reinforcer. Because a COD often increases preference, we left it out of the present work.

RESULTS

The upper three graphs in Figure 1 show the logarithm of the relative response rate (P_L/P_R) in the presence of the white keys as a function of the logarithm of the relative obtained reinforcement rate (r_l/r_r) on those keys for each subject. The bottom three graphs in Figure 1 show the logarithm of the relative time spent pecking each key (T_L/T_R) as a function of the logarithm of the relative obtained reinforcement rate (r_l/r_r) on those keys for each subject. The straight line through the data points represents the line obtained by a least-squares regression equation.

$$\ln (P_L/P_R) = a \ln (r_l/r_r) + \ln k$$

and

$$\ln (T_L/T_R) = a \ln (r_l/r_r) + \ln k$$

respectively. The values of a , the slope, and $\ln k$, the intercept, were empirically determined (Baum, 1974). The value (e) in the upper-left corner of each graph is the proportion of variance not accounted for by the regression equa-

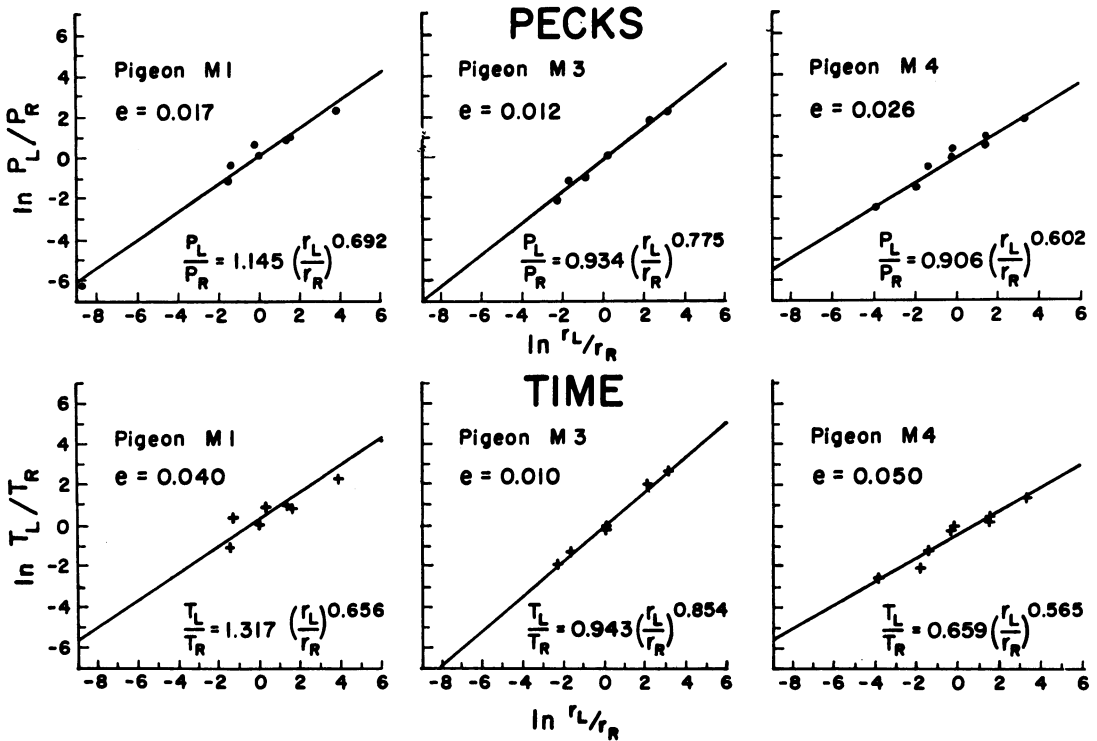


Fig. 1. The logarithm of the relative reinforcement rate plotted against the logarithm of the relative response rate (top three graphs) and the logarithm of relative time allocation (bottom three graphs). The data for M1 are on the left, for M3 in the middle, and for M4 on the right. The number in the upper-left corner of each graph is the proportion of variance unaccounted for by the best-fit regression equation given in the lower-right corner.

tion given in the lower-right corner of each graph. For all three subjects, over 95% of the variance in both response rate and time allocation was accounted for by the relative reinforcement ratio (r_L/r_R) and the parameters a and k . All data points were obtained by taking the mean proportion (left/sum of left plus right) for the last five sessions of each condition, converting this number to a relative rate (left/right) and then taking the natural logarithm. This procedure permitted the inclusion of data for sessions in which, because of the low response rates, no reinforcers were obtained on the less-preferred key (this happened in only the most extreme conditions: either *conc* VI 18.75-sec VI 168.5-sec or *conc* VI 168.5-sec VI 18.75-sec). Subject M3, however, received no reinforcers at all on the 168.5-sec side for the last five sessions of that condition. Because the log of the resultant relative ratio was indeterminate, those two data points were excluded from the analysis.

One bird (M1) showed a slight bias for the left key, as evidenced by a k value greater than one, and two birds (M3 and M4) showed a slight bias for the right key. All birds consistently "undermatched" (Baum, 1974) both time and response allocation, as revealed by the less-than-unity values obtained for the exponent a . This indicates that the measures of preference—relative time and response allocation—tended to be closer to 1.0 ($\ln = 0.0$) than the obtained relative reinforcement ratio.

Although the relative-time and response-allocation measures were systematically related to the relative reinforcement ratios, the absolute (left- plus right-key responses combined) response rates were not. Table 2 shows the overall response and obtained overall reinforcement rates and ranges, for the last five sessions in each condition. There appears to be no systematic relationship between overall response rate and relative scheduled, or obtained, reinforcement rates.

Table 2

Mean response rate for both keys combined and mean obtained reinforcement rate for the last five sessions under each condition. The upper value for each condition in column one is for the left key; the lower value is for the right key. (Ranges are shown in parentheses.)

Condition	M1		M3		M4	
	Responses/min	Reinforcers/min	Responses/min	Reinforcers/min	Responses/min	Reinforcers/min
Conc VI 67.50	19.86 (17.38-20.32)	2.93 (2.67-3.14)	12.70 (4.83-23.6)	2.21 (.93-3.18)	14.36 (12.91-15.20)	2.45 (2.34-2.59)
VI 22.50						
Conc VI 168.50	13.10 (9.90-14.68)	3.60 (3.46-3.90)	8.36 (6.38-9.95)	2.51 (1.97-2.90)	11.04 (9.96-12.54)	3.11 (2.82-3.42)
22.50						
Conc VI 67.50	17.24 (9.93-19.00)	2.70 (2.20-2.98)	6.02 (3.81-9.88)	2.18 (1.11-2.12)	15.60 (13.60-18.78)	2.39 (2.26-2.51)
VI 22.50						
Conc VI 33.75	18.75 (7.64-26.74)	2.53 (2.11-2.96)	10.24 (5.11-14.62)	1.88 (1.53-2.33)	12.40 (1.91-17.70)	2.27 (1.91-2.57)
VI 33.75						
Conc VI 22.50	17.07 (14.68-18.73)	2.57 (2.05-3.11)	10.97 (4.89-13.42)	2.07 (1.47-2.36)	13.29 (9.65-15.19)	2.21 (2.06-2.51)
VI 67.50						
Conc VI 18.75	20.21 (17.72-22.93)	3.92 (3.86-4.00)	7.08 (4.93-10.77)	2.68 (2.22-3.67)	10.01 (5.83-15.20)	2.68 (1.70-3.50)
168.50						
Conc VI 22.50	18.47 (14.58-20.77)	2.81 (2.76-3.15)	5.50 (4.12-6.88)	1.82 (1.67-1.97)	11.16 (7.44-10.87)	2.10 (1.83-2.60)
VI 67.50						
Conc VI 33.75	18.21 (17.19-20.53)	1.94 (1.62-2.26)	5.04 (3.48-6.66)	1.43 (1.36-1.50)	9.22 (7.97-11.08)	1.88 (1.61-2.08)
VI 33.75						
Mean of all Conditions	17.85	2.88	8.24	2.10	12.14	2.39

DISCUSSION

The present results suggest that the matching relationship holds for pigeons pecking a key under a concurrent negative reinforcement schedule, as has frequently been reported in experiments using positive reinforcement.

There are two implications. First, the relative value of an alternative is a function of the relative frequency of access to that alternative in concurrent VI VI schedules of negative reinforcement. de Villiers (1974) showed that absolute response rate is a function of the probability of shock-frequency reduction following a bar press by rats. The present data extend this relationship to relative rates of response.

The second implication is that both positive and negative reinforcement procedures can be parsimoniously conceptualized within the same theoretical framework. The present study, in which 1 min of shock-free time was systematically manipulated, suggests that it is a situation transition (a shock-free period or access to grain) that is fundamental in defining "reinforcement" in both positive and negative reinforcement procedures (Baum, 1973).

Although each subject's data were described by the best-fitting linear regression line relating relative reinforcement rate to relative response rate and relative time allocation, perfect matching was not found. Instead, undermatching was found for each bird with both dependent variables. Undermatching is shown when the relative-time and response-allocation measures are less extreme than the relative reinforcement ratio and occurs frequently on concurrent schedules of positive reinforcement (Myers and Myers, 1977). Baum (1974) suggested that reduced "discriminability" of the relative value of two concurrent alternatives will be reflected as undermatching. The values reported here for the exponent a (from 0.57 to 0.85) were somewhat less than those listed by Lobb and Davison (1975) for concurrent schedules of positive reinforcement. It may be that the differences are due to differences in procedure (1-min *versus* 4-sec access to the reinforcing alternatives, difficulties in equating shock and, food deprivation, *etc.*), or to more fundamental differences in the effects on key pecking controlled by positive *versus* negative reinforcement.

Some recent theorizing suggests that latter interpretation (Seligman and Hager, 1972). The concept of "preparedness" has it that some responses are more susceptible to some reinforcers than to other reinforcers. The pigeon's key-peck response is difficult to train initially using negative reinforcers and is generally considered to be contraprepared for association with shock avoidance (Seligman and Hager, 1972). The relatively small values for the exponent " a " observed in this experiment may be reflecting the fact that pigeons are contraprepared to associate key pecking with shock avoidance. Indeed, the exponent " a " has been interpreted as a measure of the subject's sensitivity to the experimental manipulation (Baum, 1974). Regardless of the meaning of the " a " values, it is clear from these data that the generalized matching law applies to contraprepared response-reinforcer relationships.

REFERENCES

- Baum, W. M. The correlation-based law of effect. *Journal of the Experimental Analysis of Behavior*, 1973, 20, 137-153.
- Baum, W. M. Two types of deviation from the matching law: bias and undermatching. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 231-242.
- de Villiers, P. A. The law of effect and avoidance: a quantitative relationship between response rate and shock-frequency reduction. *Journal of the Experimental Analysis of Behavior*, 1974, 21, 223-235.
- Herrnstein, R. J. The law of effect. *Journal of the Experimental Analysis of Behavior*, 1970, 13, 243-266.
- Hutton, L. and Lewis, P. Effects of response-independent negative reinforcers on negatively reinforced key pecking. *Journal of the Experimental Analysis of Behavior*, (in press).
- Lewis, P., Lewin, L., Muehleisen, P., and Stoyak, M. Negatively reinforced key pecking. *Journal of the Experimental Analysis of Behavior*, 1974, 22, 83-90.
- Lewis, P., Moon, L., and Hutton, L. Choice between shock-free times in concurrent avoidance schedules. *Psychonomic Bulletin*, 1976, 8, 395-398.
- Lobb, B. and Davison, M. C. Performance in concurrent internal schedules: a systematic replication. *Journal of the Experimental Analysis of Behavior*, 1975, 24, 191-197.
- Myers, D. L. and Myers, L. E. Undermatching: a reappraisal of performance on concurrent variable-interval schedules of reinforcement. *Journal of the Experimental Analysis of Behavior*, 1977, 27, 203-214.
- Seligman, M. E. P. and Hager, J. L. *Biological boundaries of learning*. Englewood Cliffs, New Jersey: Prentice-Hall, Inc., 1972.

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